Watershed Report for Biological Impairment of the Non-Tidal Rock Creek Basin in Montgomery County, Maryland Biological Stressor Identification Analysis Results and Interpretation

REVISED FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DNR	Maryland Department of Natural Resources
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biotic Integrity
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
mg/L	Milligrams per liter
MH	Mantel and Haenszel
MS4	Municipal Separate Storm Sewer System
n	Number
NPDES	National Pollution Discharge Elimination System
PSU	Primary Sampling Unit
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
μeq/L	Micro equivalent per liter
μS/cm	Micro Siemens per centimeter
USEPA	United States Environmental Protection Agency
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met.

The Rock Creek 8-digit watershed (basin number 02-14-02-06), located in Montgomery County, was identified on the Integrated Report under Category 5 as impaired by nutrients (1996 listing), suspended sediments (1996 listing), fecal bacteria (2002 listing) and evidence of impacts to biological communities (2002 listing). Two impoundments located within the basin, Needwood Lake and Lake Bernard Frank were identified as impaired by phosphorus in 1998. All impairments are listed for non-tidal streams. The 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. Water Quality Analyses for eutrophication in Needwood Lake and Lake Bernard Frank were approved by the USEPA in 2003. A TMDL to address the 2002 fecal coliform listing was approved by the USEPA in 2007.

In 2002, the State began listing biological impairments on the Integrated Report. The current MDE biological assessment methodology assesses and lists at the Maryland 8-digit watershed scale, which maintains consistency with how other listings on the Integrated Report are made, how TMDLs are developed, and how implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds with multiple impacted sites by measuring the percentage of stream miles that have an Index of Biotic Integrity (IBI) score less than 3, and calculating whether this is significant from a reference condition watershed (i.e., healthy stream, <10% stream miles with IBI <3).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Rock Creek watershed is Use III (*nontidal coldwater*) for Rock Creek and all tributaries above Muncaster Mill Road and Use IV (*recreational trout waters*) for Rock Creek and all tributaries between Route 28 and Muncaster Mill Road. The remaining mainstem and tributaries in the Rock Creek watershed are Use I-P – *water contact recreation*, *protection of nontidal warmwater aquatic life*, *and public water supply* (COMAR 2009a,b). The Rock Creek watershed is not attaining its designated use of supporting aquatic life because of biological impairments. As an indicator of designated use attainment, the Maryland Department of the Environment (MDE) uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact the stressor has on the degraded sites in the watershed.

The BSID analysis uses data available from the statewide MDDNR MBSS. Once the BSID analysis is completed, a number of stressors (pollutants) may be identified as probable or unlikely causes of poor biological conditions within the Maryland 8-digit watershed under study. BSID analysis results can be used as guidance to refine biological impairment listings in the Integrated Report by specifying the probable stressors and sources linked to biological degradation.

This Rock Creek watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and which may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the biological communities of the Rock Creek watershed are influenced by urban land use and its concomitant effects: altered hydrology and increased pollutant loading from urban runoff resulting in elevated levels of sediment, conductivity (a measure of the presence of dissolved substances) and nutrients. The urbanization of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between highly urbanized landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

The results of the BSID analysis, and the probable causes and sources of the biological impairments in the Rock Creek watershed can be summarized as follows:

- The BSID analysis has determined that biological communities in the Rock Creek watershed are likely degraded due to flow/sediment related stressors. Sediment stressors are significantly associated with degraded biological conditions and found in approximately 78% of the stream miles with poor to very poor biological conditions in the Rock Creek watershed. Specifically, altered hydrology and increased stormwater runoff from urban impervious surfaces have resulted in elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results confirm the establishment of a USEPA approved sediment TMDL in 2011 was an appropriate management action to begin addressing these stressor's impact on the biological communities in Rock Creek.

- The BSID analysis has determined that the biological communities in the Rock Creek watershed are likely degraded due to water chemistry related stressors (i.e., total phosphorus and conductivity). Water chemistry stressors are significantly associated with degraded biological conditions and found in approximately 44% of the stream miles with poor to very poor biological conditions in the Rock Creek watershed. Specifically, urbanization and associated impervious surfaces have resulted in the potential for elevated nutrient and inorganic contaminants in the watershed, which are in turn the likely causes of impacts to biological communities. While elevated nutrients and conductivity indicate that conditions, such as eutrophication and the presence of toxic inorganic pollutants, may exist in the watershed, the BSID analysis did not reveal key supporting water chemistry parameters (e.g., low DO, high pH, elevated chlorides, and sulfates) that would indicate these conditions exist at this time; therefore, further investigation is recommended. There is an existing Category 5 listing in the 2010 IR for phosphorus, and a TMDL for phosphorus is being developed; therefore, no further management actions are needed at this time.

1.0 Introduction

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met. In 2002, the State began listing biological impairments on the Integrated Report. Maryland Department of the Environment (MDE) has developed a biological assessment methodology to support the determination of proper category placement for 8-digit watershed listings.

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2008). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or blackwater streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary.

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments was limited to the round two Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) dataset (2000–2004) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

The remainder of this report provides a characterization of the Rock Creek watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Rock Creek Watershed Characterization

2.1 Location

The entire Rock Creek watershed comprises approximately 76 square miles (48,640 acres), with approximately 80% of the drainage within Montgomery County, Maryland and the remaining 20% within Washington, D.C. (District of Columbia Rock Creek TMDL, 2004) (see Figure 1). The headwaters of Rock Creek originate in Laytonsville, Maryland, and continue to flow southward through Montgomery County and Washington, D.C. until it reaches the Potomac River. The North Branch of Rock Creek headwaters are located at Mount Zion, Maryland and discharge to Rock Creek in Rockville, Maryland. There are two surface impoundments located in the Rock Creek watershed: Needwood Lake and Lake Bernard Frank. The Maryland portion of the watershed is located in the Piedmont eco-region, one of three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

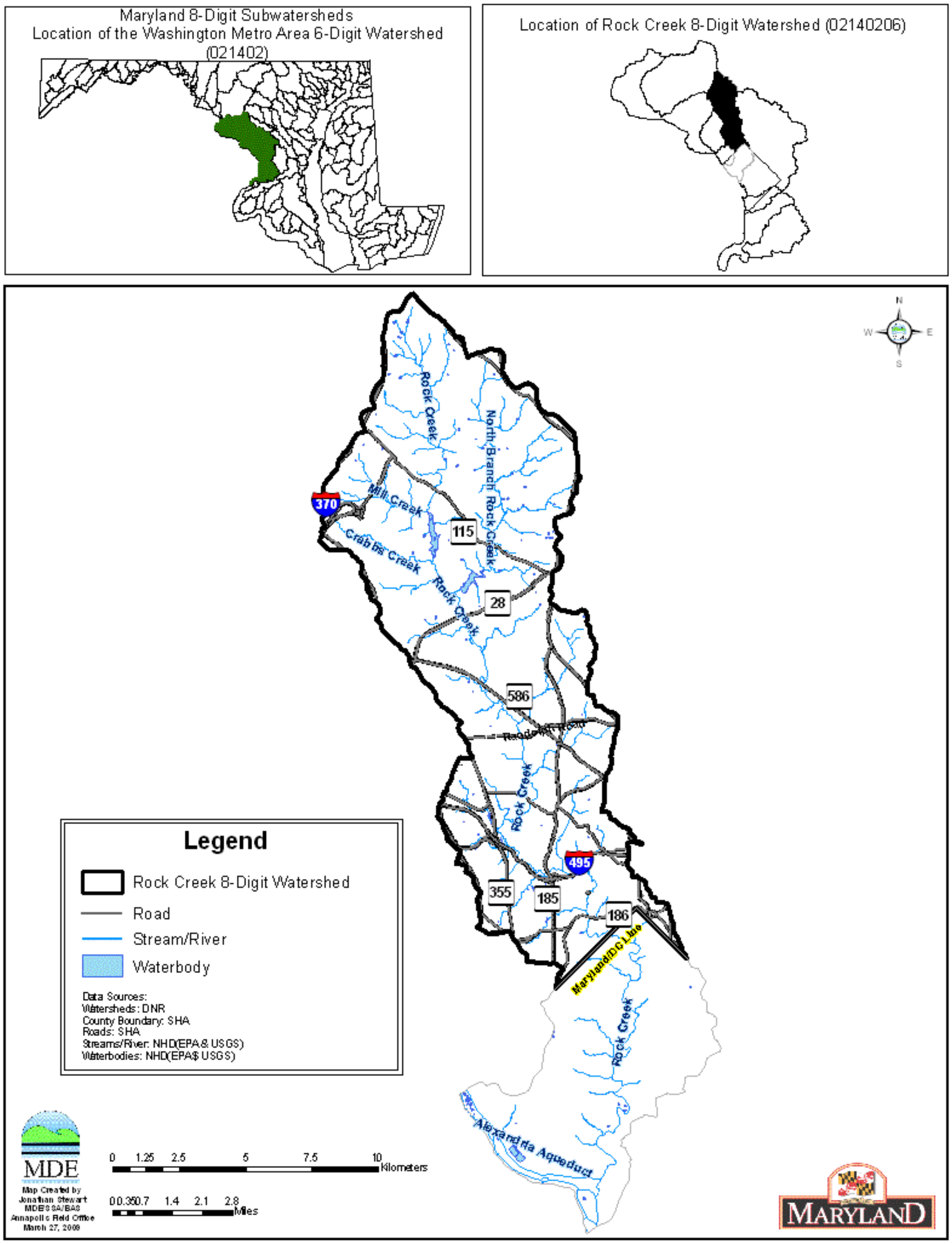

Figure 1. Location Map of the Rock Creek Watershed

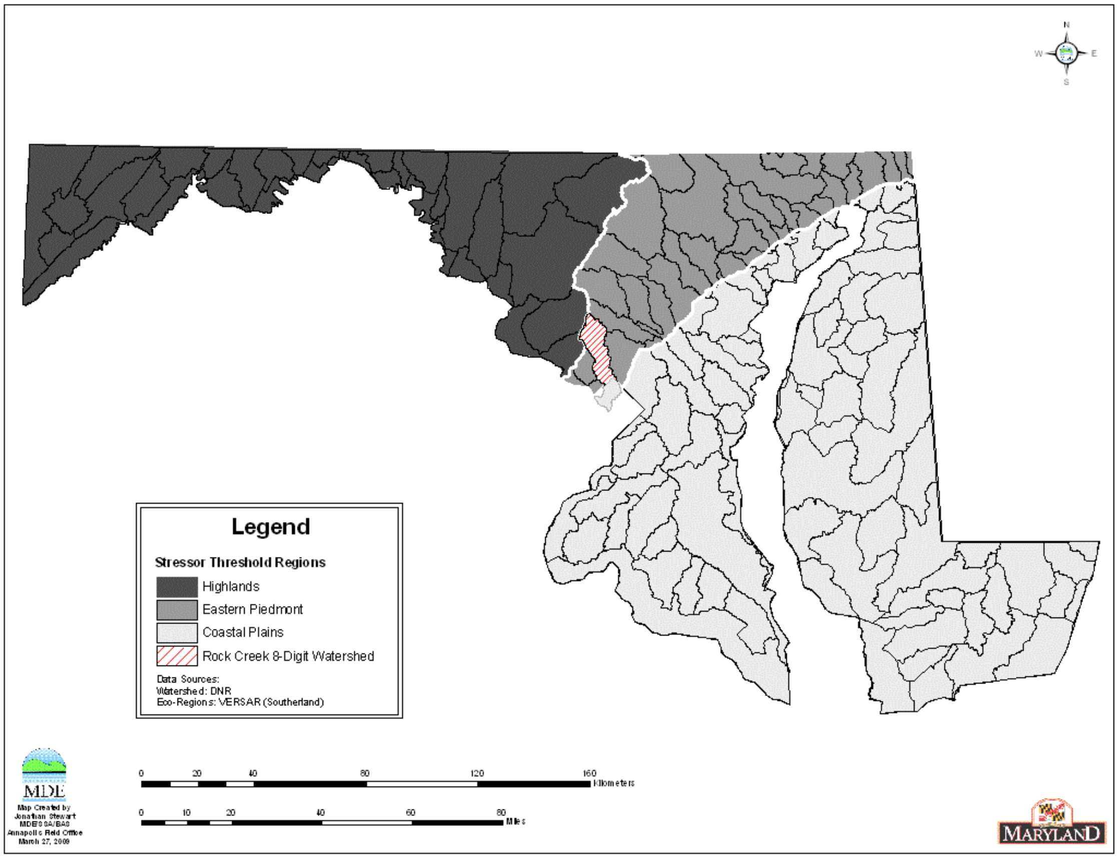

Figure 2. Eco-Region Location Map of the Rock Creek Watershed

2.2 Land Use

The Maryland portion of the Rock Creek watershed comprises 39,248 acres of drainage area in Montgomery County, Maryland. This portion of the watershed consists primarily of residential development and the Rock Creek Stream Valley Park (see Figure 3). The Rock Creek Stream Valley Park provides a protective buffer along the mainstem of Rock Creek, as well as a system of hiking and biking trails that extend from Lake Needwood to Washington, DC. Most of Lower Rock Creek is a heavily urbanized, densely populated area that was developed many years before there were requirements for managing stormwater runoff quantity and quality changes (MCDEP 2009). According to the Phase 5.2 Chesapeake Bay Watershed Model, the land use distribution in the Rock Creek 8-digit watershed consists of approximately 79% urban, 16% forest and 5% agriculture (see Figure 4). Impervious surfaces such as rooftops, paved roads and parking lots cover 19% of the urban areas in the watershed.

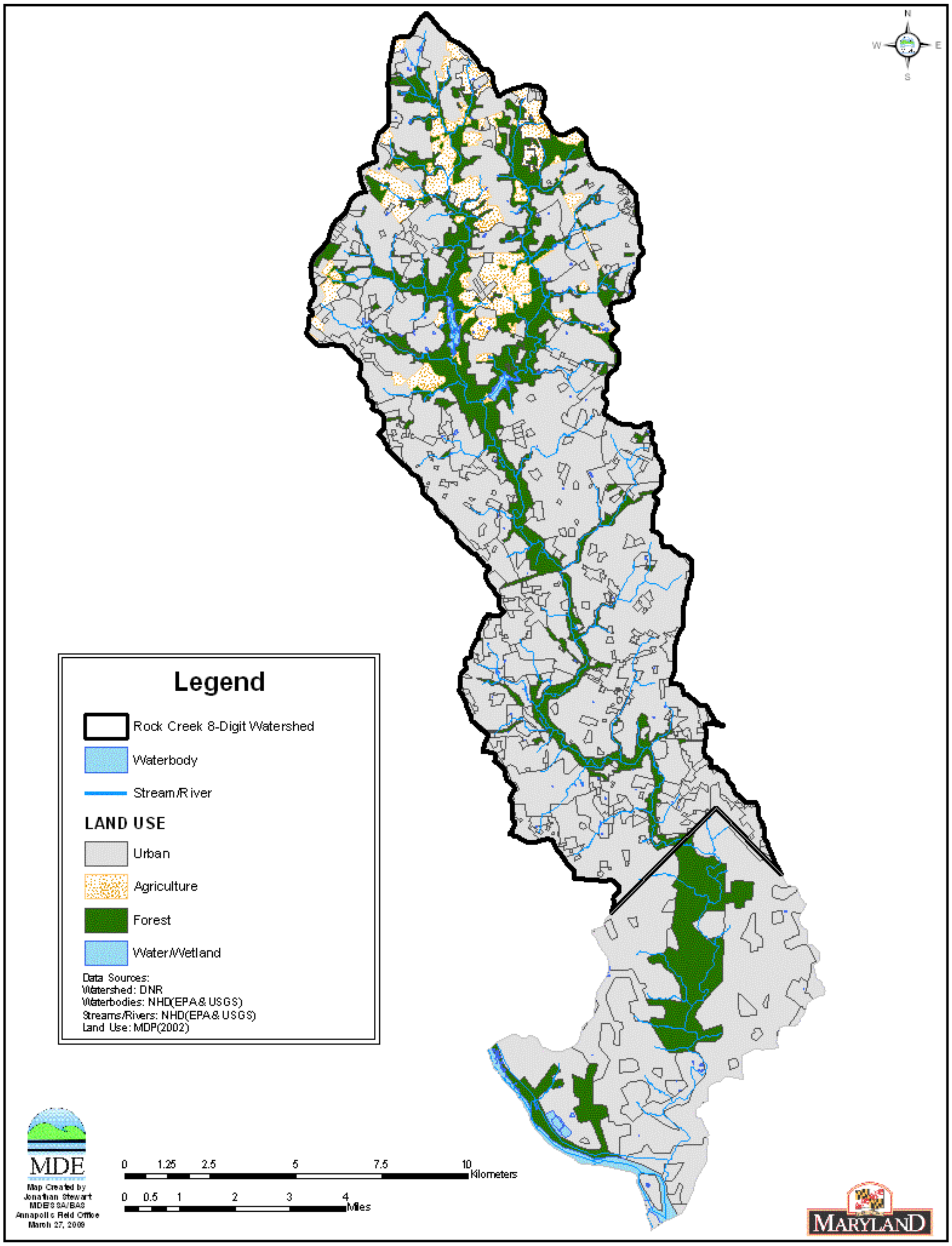

Figure 3. Land Use Map of the Rock Creek Watershed

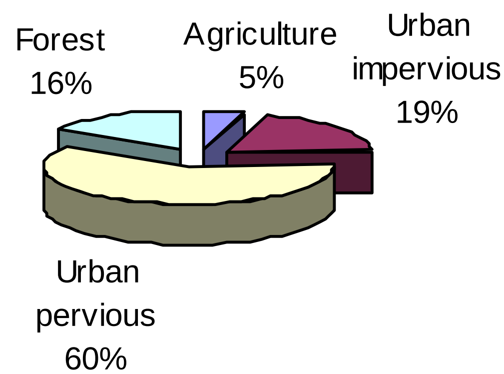

Figure 4. Proportions of Land Use in the Rock Creek Watershed

2.3 Soils/hydrology

The Rock Creek watershed extends into two physiographic provinces. In Maryland, the Rock Creek watershed is located in the Piedmont Province, where the bedrock consists of metamorphic rocks of Paleozoic age. The portion of Rock Creek located in the Washington, D.C. area lies within the Coastal Plain province. The Piedmont province is characterized by relatively narrow and steep-sloped valleys of moderately thin soils, as compared to the undulating Coastal Plain which contains deeper sedimentary soil complexes and supports broader meandering streams (Anacostia watershed network: www.anacostia.net, February 14, 2005). The North Branch and the mainstem of Rock Creek lie predominantly in the Manor-Glenelg-Chester soil series. Soils in this series are fine-loamy, mixed, mesic Typic Hapludults and are very deep and well drained soils (SCS, 1995).

3.0 Rock Creek Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Rock Creek watershed (basin number 02-14-02-06), located in Montgomery County, was identified on the Integrated Report under Category 5 as impaired by nutrients (1996 listing), suspended sediments (1996 listing), fecal bacteria (2002 listing) and evidence of impacts to biological communities (2002 listing). Two impoundments located within the watershed, Needwood Lake and Lake Bernard Frank, were identified as impaired by phosphorus in 1998. All impairments are listed for non-tidal streams. The 1996 nutrients listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Similarly, the 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. Water quality analyses for eutrophication in Needwood Lake and Lake Bernard Frank were approved by the USEPA in 2003. A TMDL for fecal coliform to address the 2002 listing was approved by the USEPA in 2007.

3.2 Biological Impairment

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the Rock Creek watershed is Use III (*noontide coldwater*) for Rock Creek and all tributaries above Muncaster Mill Road and Use IV (*recreational trout waters*) for Rock Creek and all tributaries between Route 28 and Muncaster Mill Road. The remaining mainstem and tributaries in the Rock Creek watershed are Use I-P – *water contact recreation*, *protection of nontidal warmwater aquatic life*, *and public water supply* (COMAR 2009a,b). A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life, primary or secondary contact recreation, drinking water supply, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Rock Creek watershed is listed under Category 5 of the 2008 Integrated Report as impaired for evidence of biological impacts. Fifty-six percent of the stream miles in the Rock Creek watershed are estimated as degraded based on benthic and and/or fish indices of biological impairment in the very poor to poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include eighteen stations. Ten of the eighteen stations have degraded benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., very poor to poor). The principal dataset, i.e., MBSS Round 2, contains nine MBSS sites (one located within Washington, DC); six have BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Rock Creek watershed.

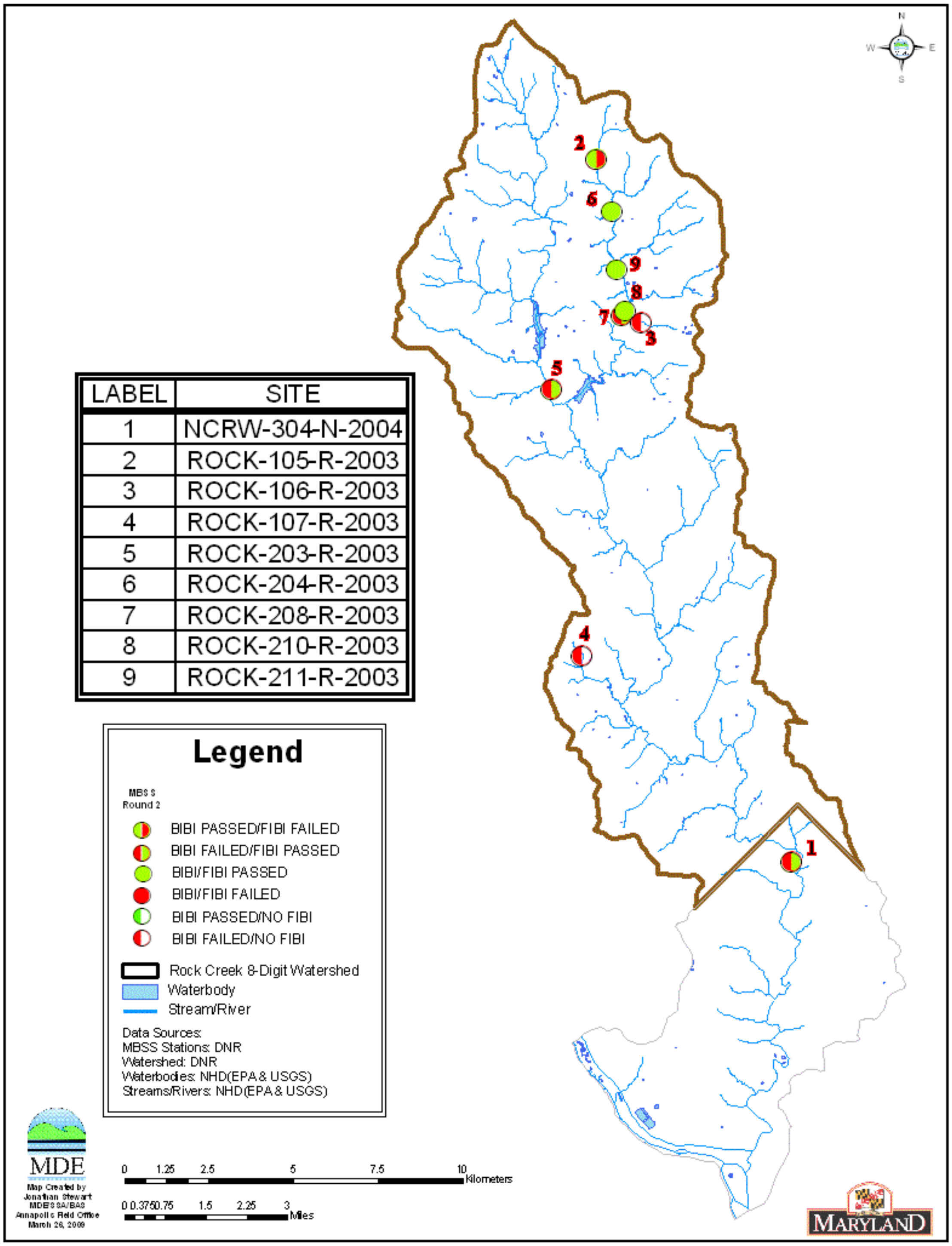

Figure 5. Principal Dataset Sites for the Rock Creek Watershed

4.0 Stressor Identification Results

The BSID process uses results from the BSID data analysis to evaluate each biologically impaired watershed and determine potential stressors and sources. Interpretation of the BSID data analysis results is based upon components of Hill's Postulates (Hill 1965), which propose a set of standards that could be used to judge when an association might be causal. The components applied are: 1) the strength of association which is assessed using the odds ratio; 2) the specificity of the association for a specific stressor (risk among controls); 3) the presence of a biological gradient; 4) ecological plausibility which is illustrated through final causal models; and 5) experimental evidence gathered through literature reviews to help support the causal linkage.

The BSID data analysis tests for the strength of association between stressors and degraded biological conditions by determining if there is an increased risk associated with the stressor being present. More specifically, the assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group (odds ratio). The case group is defined as the sites within the assessment unit with BIBI/FIBI scores lower than 3.0 (i.e., poor to very poor). The controls are sites with similar physiographic characteristics (Highland, Eastern Piedmont, and Coastal region), and stream order for habitat parameters (two groups – 1^{st} and 2^{nd}-4th order), that have good biological conditions.

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (MH) (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are very poor to poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and very poor to poor biological conditions and is used to identify potential stressors.

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with very poor to poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with very poor to poor biological conditions that are associated with the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

Once the AR is defined for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a group of stressors is also summed over the case sites using the individual site characteristics (i.e., stressors present at that site). The only difference is that the absolute risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls.

After determining the AR for each stressor and the AR for groups of stressors, the AR for all potential stressors is calculated. This value represents the proportion of cases, sites in the watershed with poor to very poor biological conditions, which would be improved if the potential stressors were eliminated (Van Sickle and Paulsen 2008). The purpose of this metric is to determine if stressors have been identified for an acceptable proportion of cases (MDE 2009).

Through the BSID data analysis, MDE identified sediment and water chemistry parameters, and potential sources significantly associated with poor to very poor fish and/or benthic biological conditions. As shown in Table 1 through Table 3, parameters from the sediment and water chemistry groups are identified as possible biological stressors in the Rock Creek watershed. Parameters identified as representing possible sources are listed in Table 4 and include various urban land use types. Table 5 shows the summary of combined AR values for the stressor groups in the Rock Creek watershed. Table 6 shows the summary of combined AR values for the source groups in the Rock Creek watershed.

Table 1. Sediment Biological Stressor Identification Analysis Results for the Rock Creek Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (Number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata1 with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata1 with stressor present	Possible stressor (Odds of stressor in cases significant ly higher that odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Sediment	extensive bar formation present	9	6	82	50%	13%	Yes	37%
	moderate bar formation present	9	6	82	83%	43%	Yes	40%
	bar formation present	9	6	82	100%	91%	No	----
	channel alteration marginal to poor	9	6	82	100%	42%	Yes	57%
	channel alteration poor	9	6	82	67%	12%	Yes	55%
	high embeddedness	9	6	82	0%	9%	No	----
	epifaunal substrate marginal to poor	9	6	82	33%	11%	No	----
	epifaunal substrate poor	9	6	82	17%	2%	No	----
	moderate to severe erosion present	9	6	82	50%	61%	No	----
	severe erosion present	9	6	82	33%	13%	No	----
	poor bank stability index	9	6	82	17%	4%	No	----
	silt clay present	9	6	82	100%	100%	No	----

Table 2. Habitat Biological Stressor Identification Analysis Results for the Rock Creek Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (Number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata1 with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata1 with stressor present	Possible stressor (Odds of stressor in cases significantly higher that odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	9	6	83	33%	10%	No	----
	instream habitat structure marginal to poor	9	6	82	17%	10%	No	----
	instream habitat structure poor	9	6	82	0%	1%	No	----
	pool/glide/eddy quality marginal to poor	9	6	82	17%	39%	No	----
	pool/glide/eddy quality poor	9	6	82	0%	1%	No	----
	riffle/run quality marginal to poor	9	6	82	17%	15%	No	----
	riffle/run quality poor	9	6	82	0%	1%	No	----
	velocity/depth diversity marginal to poor	9	6	82	17%	40%	No	----
	velocity/depth diversity poor	9	6	82	0%	0%	No	----
	concrete/gabion present	9	6	83	17%	2%	No	----
	beaver pond present	9	6	82	0%	3%	No	----
Riparian Habitat	no riparian buffer	9	6	83	33%	22%	No	----
	low shading	9	6	82	0%	8%	No	----

Table 3. Water Chemistry Biological Stressor Identification Analysis Results for the Rock Creek Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (Number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata1 with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites per strata1 with stressor present	Possible stressor2 (Odds of stressor in cases significantly higher that odds or stressors in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	9	6	165	0%	47%	No	----
	ammonia acute with salmonid present	9	6	165	17%	5%	No	----
	ammonia acute with salmonid absent	9	6	165	17%	3%	No	----
	ammonia chronic with salmonid present	9	6	165	33%	15%	No	----
	ammonia chronic with salmonid absent	9	6	165	17%	4%	No	----
	low lab pH	9	6	165	0%	2%	No	----
	high lab pH	9	6	165	17%	2%	No	----
	low field pH	9	6	164	0%	4%	No	----
	high field pH	9	6	164	0%	2%	No	----
	high total phosphorus	9	6	165	33%	6%	Yes	27%
	high orthophosphate	9	6	165	17%	8%	No	----
	dissolved oxygen < 5mg/l	9	6	164	0%	1%	No	----
	dissolved oxygen < 6mg/l	9	6	164	0%	2%	No	----
	low dissolved oxygen saturation	8	5	152	0%	1%	No	----
	high dissolved oxygen saturation	8	5	152	0%	0%	No	----
	acid neutralizing capacity below chronic level	9	6	165	0%	1%	No	----
	acid neutralizing capacity below episodic level	9	6	165	0%	7%	No	----
	high chlorides	9	6	165	17%	5%	No	----
	high conductivity	9	6	165	33%	6%	Yes	27%
	high sulfates	9	6	165	17%	4%	No	----

Table 4. Stressor Source Identification Analysis Results for the Rock Creek Watershed

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites per strata1 with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites per strata1 with source present	Possible stressor2 (Odds of stressor in cases significantly higher that odds or sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources - Urban	high impervious surface in watershed	9	6	164	67%	3%	Yes	64%
	high % of high intensity urban in watershed	9	6	165	100%	21%	Yes	79%
	high % of low intensity urban in watershed	9	6	165	67%	5%	Yes	61%
	high % of transportation in watershed	9	6	165	67%	9%	Yes	58%
	high % of high intensity urban in 60m buffer	9	6	164	17%	4%	No	----
	high % of low intensity urban in 60m buffer	9	6	164	50%	6%	Yes	44%
	high % of transportation in 60m buffer	9	6	164	0%	6%	No	----
Sources - Agr	high % of agriculture in watershed	9	6	165	0%	22%	No	----
	high % of cropland in watershed	9	6	165	0%	3%	No	----
	high % of pasture/hay in watershed	9	6	165	0%	29%	No	----
	high % of agriculture in 60m buffer	9	6	164	0%	13%	No	----
	high % of cropland in 60m buffer	9	6	164	0%	3%	No	----
	high % of pasture/hay in 60m buffer	9	6	164	17%	23%	No	----
Sources - Barren	high % of barren land in watershed	9	6	165	17%	10%	No	----
	high % of barren land in 60m buffer	9	6	164	17%	10%	No	----
Sources - Anthropogenic	low % of forest in watershed	9	6	165	33%	8%	Yes	25%
	low % of forest in 60m buffer	9	6	164	33%	9%	Yes	25%
Sources - Acidity	atmospheric deposition present	9	6	165	0%	5%	No	----
	AMD acid source present	9	6	165	0%	0%	No	----
	organic acid source present	9	6	165	0%	0%	No	----
	agricultural acid source present	9	6	165	0%	2%	No	----

Table 5. Summary of Combined Attributable Risk Values for the Stressor Groups in the Rock Creek Watershed

Stressor Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Sediment	78%	86%
In-Stream Habitat	----	
Riparian Habitat	----	
Water Chemistry	44%	

Table 6. Summary of Combined Attributable Risk Values for the Source Groups in the Rock Creek Watershed

Source Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Urban	96%	96%
Agriculture	----	
Barren Land	----	
Anthropogenic	25%	
Acidity	----	

Sediment Conditions

BSID analysis results for the Rock Creek watershed identified four sediment parameters that have a statistically significant association with poor to very poor stream biological condition: *bar formation (moderate* and *extensive) and channel alteration (marginal to poor* and *poor).*

Bar formation was identified as significantly associated with degraded biological conditions and found in 40% (*moderate* rating) and 37% (*extensive* rating) of the stream miles with poor to very poor biological conditions in the Rock Creek watershed. This stressor measures the movement of sediment in a stream system, and typically results from significant deposition of gravel and fine sediments. Although some bar formation is natural, extensive bar formation indicates channel instability related to frequent and intense high flows that quickly dissipate and rapidly lose the capacity to transport the sediment loads downstream. Excessive sediment loading is expected to reduce and homogenize available feeding and reproductive habitat, degrading biological conditions.

Channel alteration (marginal to poor and *poor)* was identified as significantly associated with degraded biological conditions and found to impact 57% (*marginal to poor* rating) and 55% (*poor* rating) of the stream miles with poor to very poor biological conditions in the Rock Creek watershed. Channel alteration measures large-scale modifications in the shape of the stream channel due to the presence of artificial structures (channelization) and/or *bar formations*. A marginal to poor or poor rating is expected in unstable stream channels that experience frequent high flows.

The majority of the Rock Creek watershed is comprised of urban land uses. As development and urbanization increase in a watershed, so do the morphological changes that affect a stream's habitat. The most critical of these environmental changes are those that alter the watershed's hydrologic regime. Changes to hydrographs are perhaps the most obvious and consistent changes to stream ecosystems influenced by urban land use, with urban streams tending to be more "flashy", i.e., they have more frequent, larger flow events (Walsh et al. 2005). The scouring associated with these increased flows can lead to accelerated channel alteration and erosion, thereby increasing sediment deposition throughout the streambed either through the formation of bars or settling of sediment in the stream substrate. These processes create an unstable stream ecosystem that can result in a loss of available habitat, continuous displacement of biological communities, frequent re-colonization of biological communities, and a shift in biological communities (i.e, sensitive taxa replaced by more tolerant species).

The urbanization and ensuing flashiness of Rock Creek has resulted in significant channel alteration and bar formation within the watershed, as demonstrated by the statistically significant stressors associated with the sediment condition. The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for the sediment stressor group is approximately 78% suggesting that this stressor impacts a substantial proportion of degraded stream miles in the Rock Creek watershed (Table 5).

In-stream Habitat Conditions

BSID analysis results for the Rock Creek watershed did not identify any in-stream habitat parameters that have a statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in an improved biological community).

Riparian Habitat Conditions

BSID analysis results for the Rock Creek watershed did not identify any riparian habitat parameters that have a statistically significant association with a very poor to very poor stream biological condition (i.e., removal of stressors would result in an improved biological community).

Water Chemistry

BSID analysis results for the Rock Creek watershed identified two water chemistry parameters that have a statistically significant association with a poor to very poor stream biological condition: *high conductivity* and *high total phosphorus.*

High conductivity was identified as significantly associated with degraded biological conditions and found in 27% of the stream miles with poor to very poor biological conditions in the Rock Creek watershed. Conductivity is a measure of water's ability to conduct electrical current and is directly related to the total dissolved salt content of the water. Most of the total dissolved salts of surface waters are comprised of inorganic compounds or ions such as chloride, sulfate, carbonate, sodium, and phosphate (IDNR 2008). Urban runoff, road salts, fertilizers, and leaking wastewater infrastructure are typical sources of inorganic compounds. Conductivity levels typically increase in watersheds where urban land uses are predominant.

High total phosphorus levels are significantly associated with degraded biological conditions and found in approximately 27% of the stream miles with poor to very poor biological conditions in the Rock Creek watershed. Total Phosphorus (TP) is a measure of the amount of TP in the water column. Phosphorus occurs naturally in rocks and other mineral deposits, and is usually found in the form of phosphates in natural waters. Anthropogenic sources of phosphorus are fertilizers, chemicals, animal wastes and municipal sewage. TP input to surface waters typically increases in watersheds where urban or agricultural land uses are predominant.

The water chemistry stressors (conductivity and TP) identified by the BSID can be indicative of anthropogenic activities that degrade water quality by causing an increase in nutrient and inorganic contaminant loads from various point and nonpoint sources.

Conductivity can serve as an indicator that a pollution discharge or some other source of inorganic contaminant has entered a stream. Increased levels of inorganic pollutants can be toxic to aquatic organisms and lead to exceedences in species tolerances. In most urban watersheds elevated conductivity reflects heightened dissolved ion concentrations in the water, it is affected predominately by the presence of chlorides and sulfates; streams with elevated levels of these inorganic ions typically display high conductivity. Currently, in Maryland there are no specific numeric criteria that quantify the impact of conductivity on the aquatic health of non-tidal stream systems. Only two of the nine stations used in the BSID analysis reported elevated conductivities above the threshold of 300 µS/cm – (313 and 387 µS/cm). Since the BSID analysis for the watershed did not identify any of the major contributors (sulfates and chlorides) of elevated conductivity, further investigation is warranted.

Phosphorus can be toxic to aquatic organisms at very high levels but usually impacts aquatic communities indirectly, in conjunction with other stressors and/or environmental conditions. For instance, excessive phosphorus concentrations in surface water can accelerate eutrophication, resulting in increased growth of undesirable algae and aquatic weeds. Eutrophication results in low dissolved oxygen and high pH levels, which can exceed tolerance levels of many biological organisms. Since the BSID analysis for the watershed did not identify dissolved oxygen, pH, orthophosphate or nitrogen as having a significant association with degraded biological conditions, there is no supporting evidence that excessive primary production is occurring in the watershed, at this time.

The BSID analysis suggests that water chemistry stressors are present in the Rock Creek watershed. Elevated total phosphorus and conductivity are both often associated with urbanized watersheds. These parameters do not typically impact aquatic communities directly. Rather, they serve as indicators of conditions, such as eutrophication and the presence of toxic inorganic pollutants that may lead to biological impairment. Since the BSID analysis did not reveal key supporting water chemistry parameters (e.g., low DO, high pH, elevated chlorides, and sulfates) that would support these conditions at this time, additional analysis of historical, as well as future monitoring data for phosphorus, conductivity, and other supporting water chemistry parameters will help determine the spatial and temporal extent of this impairment in the watershed.

The combined AR is used to measure the extent of stressor impact of degraded stream miles, poor to very poor biological conditions. The combined AR for water chemistry stressor group is approximately 44% suggesting that these stressors impact a moderate proportion of degraded stream miles in the Rock Creek watershed (Table 5).

Sources

All six stressor parameters, identified in Tables 1-3, that are significantly associated with biological degradation in the Rock Creek watershed BSID analysis are representative of impacts from urban landscapes. The scientific community has consistently reported negative impacts to biological conditions as a result of increased urbanization and imperviousness (Paul and Meyer 2001, CWP 2000). A number of systematic and predictable environmental responses have been noted in streams affected by urbanization, and this consistent sequence of effects has been termed "urban stream syndrome" (Meyer et al. 2005). Consistent symptoms of urban stream syndrome include altered channel morphology, flashier hydrographs, elevated levels of nutrients and contaminants, and reduced biotic richness, with increased dominance of tolerant species (Meyer et al. 2005, Walsh et al. 2005).

The BSID source analysis (Table 4) identified various types of urban land uses as potential sources of stressors that may cause negative biological impacts. The *low % of forest land use* represents anthropogenic sources and is likely a result of the increased urbanization in the watershed. The combined AR for the source group is approximately 96% suggesting that urban development impacts a substantial proportion of the degraded stream miles in Rock Creek watershed (See Table 6).

Summary

The Rock Creek watershed is a highly urbanized watershed (75%), with approximately 19% impervious surface cover. Beyond thresholds of 8 to 12% total imperviousness, biological conditions decline sharply with small increments in impervious surface (Wang and Lyons 2003). The results of the BSID analysis suggest that degraded biological communities in the Rock Creek watershed are due to urbanization that has caused alterations to the hydrologic regime and stream morphology. These altered conditions have led to frequent high flow events and increased sediment loads, resulting in an unstable stream ecosystem that eliminates optimal habitat, displaces biological communities, and causes a shift in the biological community structure. Many studies have shown that as a watershed becomes more urbanized, fish and benthic communities exhibit a shift away from sensitive species to assemblages consisting of mostly disturbance-tolerant taxa (Walsh et al. 2005).

The results of the BSID analysis also suggest that water chemistry parameters are degrading biological communities in the Rock Creek watershed. Based on the high percentage of urban land use and imperviousness, and the BSID determination that urban sources impact a substantial proportion of the degraded stream miles in the watershed, it is likely that water chemistry stressors are impacting the Rock Creek watershed. While the water chemistry parameters identified do not typically impact aquatic communities directly, they do serve as indicators of conditions, such as eutrophication and the presence of toxic inorganic pollutants that may lead to biological impairment. Since the BSID analysis did not reveal key supporting water chemistry parameters that would support these conditions at this time; further analysis of additional water chemistry data, as well as additional monitoring of phosphorus, conductivity, and other supporting water chemistry parameters is warranted.

The combined AR for all the stressors is approximately 86%, suggesting that sediment and water chemistry stressors identified in the BSID analysis likely account for the biological impairment in the Rock Creek watershed (Table 5).

The BSID analysis evaluates numerous key stressors using the most comprehensive data sets available that meet the requirements outlined in the methodology report. It is important to recognize that stressors could act independently or act as part of a complex causal scenarios (e.g., eutrophication, urbanization, habitat modification). Also, uncertainties in the analysis could arise from the absence of unknown key stressors and other limitations of the principal data set. The results are based on the best available data at the time of evaluation.

Final Casual Model for the Rock Creek Watershed

Casual model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr, 1991 and USEPA 2007). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final casual model for the Rock Creek watershed, with pathways bolded or highlighted to show the watershed's probable stressors as indicated by the BSID analysis.

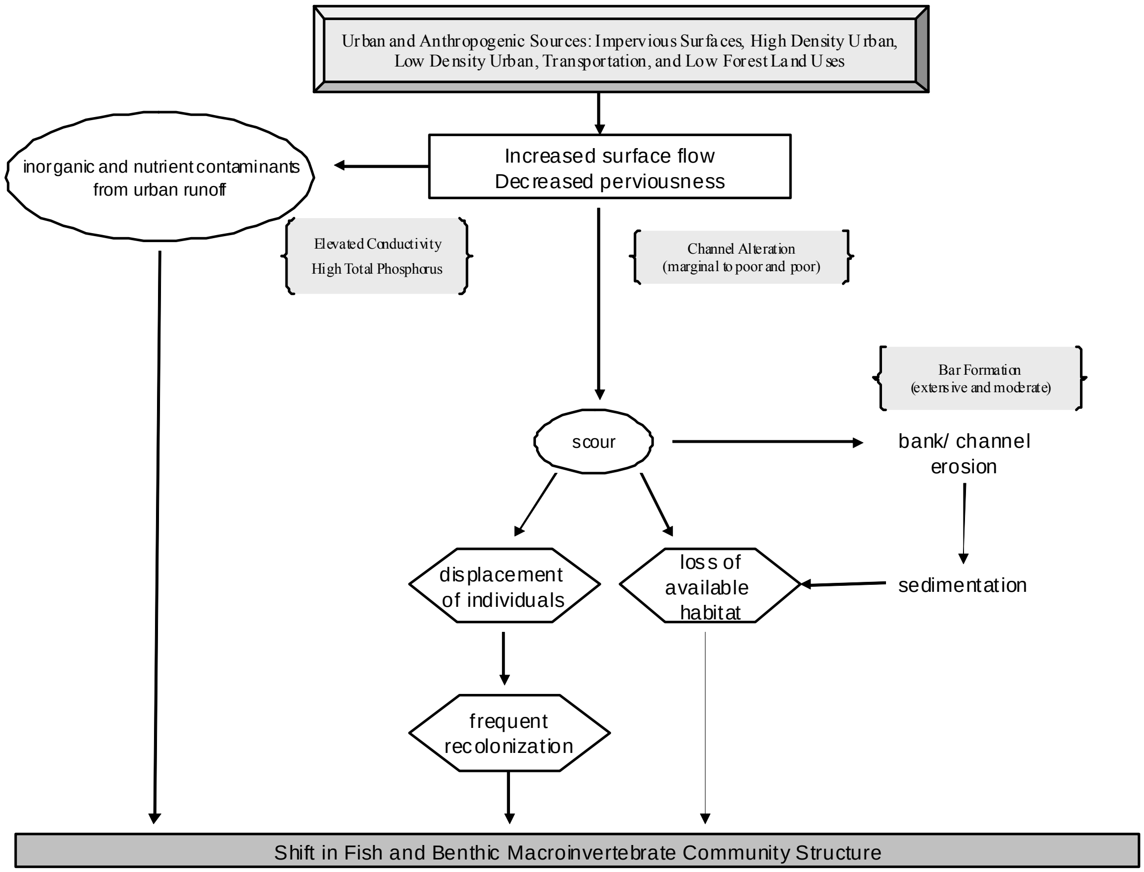

Figure 6. Final Causal Model for the Rock Creek Watershed

5.0 Conclusion

Data suggest that the Rock Creek watershed’s biological communities are strongly influenced by urban land use, which alters the hydrologic regime resulting in increased erosion, nutrient, and inorganic pollutant loading. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to urban landscapes, which often cause flashy hydrology in streams and increased contaminant loads from runoff. Based upon the results of the BSID analysis, the probable causes and sources of the biological impairments of the Rock Creek watershed are summarized as follows:

- The BSID analysis has determined that biological communities in the Rock Creek watershed are likely degraded due to flow/sediment related stressors. Sediment stressors are significantly associated with degraded biological conditions and found in approximately 78% of the stream miles with poor to very poor biological conditions in the Rock Creek watershed. Specifically, altered hydrology and increased stormwater runoff from urban impervious surfaces have resulted in elevated suspended sediment transport through the watershed, which are in turn the probable causes of impacts to biological communities. The BSID results confirm the establishment of a USEPA approved sediment TMDL in 2011 was an appropriate management action to begin addressing the impacts of these stressors on the biological communities in Rock Creek.

- The BSID analysis has determined that the biological communities in the Rock Creek watershed are likely degraded due to water chemistry related stressors (i.e., total phosphorus and conductivity). Water chemistry stressors are significantly associated with degraded biological conditions and found in approximately 44% of the stream miles with poor to very poor biological conditions in the Rock Creek watershed. Specifically, urbanization and associated impervious surfaces have resulted in the potential for elevated nutrient and inorganic contaminants in the watershed, which are in turn the likely causes of impacts to biological communities. While elevated nutrients and conductivity indicate that conditions, such as eutrophication and the presence of toxic inorganic pollutants, may exist in the watershed, the BSID analysis did not reveal key supporting water chemistry parameters (e.g., low DO, high pH, elevated chlorides, and sulfates) that would indicate these conditions exist at this time; therefore, further investigation is recommended. There is an existing Category 5 listing in the 2010 IR for phosphorus, and a TMDL for phosphorus is being developed; therefore, no further management actions are needed at this time.

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